

Appendix C

Tier 1 Uncertainty Analysis of Emissions Estimates

Overview

The *Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories*,¹ as established at the UNFCCC 4th Conference of the Parties in Kyoto, Japan in December 1997, recommend that nations carry out analyses to estimate the uncertainty in their national greenhouse gas emissions inventories. According to the guidelines, nations should construct 95 percent confidence intervals for their greenhouse gas emission estimates using classical sampling techniques, Monte Carlo techniques, or assessments by national experts. The UNFCCC subsequently requested that the IPCC complete its work on uncertainty and prepare a report on good practice in inventory management. In 2000, the IPCC issued its report *Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories*.² The report established Tier 1 and Tier 2 methods of estimating uncertainty in greenhouse gas inventories as follows:³

- Tier 1: Estimation of uncertainties by source category using error propagation equations ... and simple combination of uncertainties by source category to estimate overall uncertainty for one year and the uncertainty in the trend.
- Tier 2: Estimation of uncertainties by source category using Monte Carlo analysis, followed by the use of Monte Carlo techniques to estimate overall uncertainty for one year and the uncertainty in the trend.

EIA in 1998, in response to the IPCC's good practices guidelines, carried out a Tier 1 uncertainty analysis of U.S. greenhouse gas emissions. This was done for carbon dioxide, methane, nitrous oxide, and other gases. The results of this analysis can be found in Table C1 below. The Tier 1 analysis provides a "weighted uncertainty" for each source calculated as the squared root of the sum of the squared activity factor and emission factor errors multiplied by the point estimate of the share of total emissions for the source. The Tier 1 approach, however, as pointed out by the IPCC may be inappropriate when combining non-normal distributions, as may be the case with some of the distributions for emissions factors and activities.

EIA recently undertook a "Tier 2" uncertainty analysis of U.S. carbon dioxide, methane and nitrous oxide emission estimates to augment its previous "Tier 1" uncertainty analysis. The Tier 2 uncertainty analysis involves Monte Carlo simulations that facilitate the combination of various types of probability density functions. The preliminary results of that analysis appear in a Box at the end of Chapter 1 of this report.

For either "Tier I" or "Tier II" analysis the sources of uncertainty fall into the categories outlined below:

- Uncertainty associated with underlying activity data and uncertainty associated with emissions factors
- Random errors and bias errors
- Potential for upward and downward bias errors
- Reliability of emissions estimates by source.

¹Intergovernmental Panel on Climate Change, *Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories*, 1997.

²Intergovernmental Panel on Climate Change, *Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories*, May 2000.

³Intergovernmental Panel on Climate Change, *Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories*, May 2000, p. 6.12.

The Tier 1 uncertainty analysis found in Table C1 excludes estimates for emissions and sequestration from land use changes and forestry. The Tier 1 analysis concluded that U.S. national greenhouse gas emissions, taken as a group, may differ by as much as 13 percent from the estimates published in the earlier edition of this report. Much of the uncertainty in national emissions was attributable to estimates of nitrous oxide emissions. If nitrous oxide emissions were excluded, the uncertainty of the total estimate was calculated to be on the order of 10 percent. As a point of comparison, the Tier 2 analysis, delineated in Chapter 1, estimated total uncertainty about a simulated mean of total carbon dioxide, methane and nitrous oxide emissions⁴ to be -4.4% to 4.6%. When expressed as a percentage of total estimated 1999 emissions⁵, the uncertainty becomes -0.4 to 9.0%.

The bulk of the potential uncertainty in the overall national estimate takes the form of bias errors, which are likely to persist from one year to the next and, thus, have relatively little influence on trends, rather than random errors, which would increase the difficulty of determining whether or not a trend exists. This is because estimates of energy-related carbon dioxide are probably accurate to well within 10 percent of estimated emissions, and energy-related carbon dioxide accounts for 81 percent of national emissions of greenhouse gases. There are much larger uncertainties for methane and, particularly, for nitrous oxide emissions, but the present evidence suggests that emissions from these sources accounts for only a small portion of total emissions.

The uncertainties in the estimates presented in this report come from the following sources:

- **Evolving Definitions.** In general, this report attempts to measure “anthropogenic” (human-caused) emissions and sequestration of greenhouse gases in the United States, excluding carbon emissions of biological origin. Although in most cases it is obvious whether emissions from a particular source fall within this definition, there are a number of ambiguous cases, and the range of accepted definitions has shifted over time. Since the first edition of this report, sulfur hexafluoride has been added to the generally accepted definition of “greenhouse gases.” Emissions from bunker fuel are now excluded from the definition of “U.S. emissions.” Definitional changes tend to raise or lower emission estimates systematically.
- **Emissions Sources Excluded From the Report.** An estimate that excludes some sources will be biased downward by the amount of the excluded source. Of course, if the existence or magnitude of the excluded emissions were known, they would be included. But it is probable that there are still sources that have not yet been identified and escape inclusion in both the estimates and the list of sources excluded.
- **Incorrect Models of Emissions Processes.** An estimate based on a belief that emissions are caused by (or can be estimated from) a particular activity or process can produce large, systematically biased errors if the emissions are actually caused by some other process. The incorrect method can produce estimates that are considerably higher or lower than actual emissions and have different time-series properties.
- **Errors in Emissions Factors.** Errors in emissions factors can have diverse causes, the most common of which are definitional errors, sampling errors, and measurement errors. These errors can be either random or systematic.
- **Errors in Activity Data.** Activity data are also subject to definitional errors, frame errors, sampling errors, and measurement errors, which can be either random or systematic.
- **Computational Errors.** Computational errors can exist in the estimation of emissions factors by EIA, in the calculation of emissions by EIA, or in the computation of the underlying activity data by the source organization.

⁴It is important to point out that the Tier 1 analysis includes all UNFCCC greenhouse gases while the Tier 2 analysis does not include HFCs, PFCs and SF₆ emissions in its simulation. The inclusion of these gases, which represent approximately 2.5 percent of total U.S. greenhouse gases, would have increased the uncertainty band in the Tier 2 analysis.

⁵ Total 1999 emissions of carbon dioxide, methane and nitrous oxide as estimated in *EIA, Emissions of Greenhouse Gases in the United States 1999*, DOE/EIA-0573(99), October 2000.

Table C1. Estimate of the Reliability of 1999 U.S. Emissions Estimates (Tier 1 Method)

Table 6.1: Estimate of the Reliability of 1995 U.S. Emissions Estimates (Tier 1 Method)									
Greenhouse Gas Source	Share of Total Emissions	Activity Data			Emissions Factor			Weighted by Total Emissions	
		Bias			Bias				
		Min	Max	Random	Min	Max	Random	min	max
<-----Percent of Source-----> Percent of Total									
Carbon Dioxide									
Petroleum	35.2%	2.1%	2.4%	0.5%	1.7%	1.7%	0.5%	1.0%	1.1%
Coal	29.9%	0.6%	4.3%	0.6%	1.0%	1.0%	0.5%	0.4%	1.4%
Natural Gas	17.2%	0.5%	2.8%	0.5%	0.0%	0.0%	0.4%	0.1%	0.5%
Other	0.6%	-9.3%	7.8%	11.1%	23.3%	23.3%	4.4%	0.2%	0.2%
Missing Sources	0.0%	0.0%	0.7%	0.0%	0.0%	0.0%	0.0%	0.0%	0.4%
Total	82.9%	1.1%	3.7%	0.6%	1.2%	1.2%	0.5%	1.7%	3.5%
Methane									
Energy-Related	3.2%	13.2%	14.0%	4.9%	20.8%	25.0%	4.5%	0.8%	0.9%
Agricultural	2.8%	3.1%	5.0%	3.0%	36.4%	36.4%	10.6%	1.1%	1.1%
Industrial & Waste	3.2%	9.7%	29.4%	5.0%	50.5%	13.8%	10.1%	1.6%	1.1%
Missing Sources	0.0%	0.0%	4.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Total	9.2%	8.9%	20.6%	4.3%	35.9%	24.6%	8.3%	3.5%	3.1%
Nitrous Oxide									
Energy-Related	1.3%	0.5%	2.8%	0.5%	55.0%	200.0%	10.0%	0.7%	2.5%
Agricultural	4.1%	4.0%	5.0%	4.5%	90.0%	100.0%	10.0%	3.7%	4.1%
Industrial & Waste	0.4%	2.8%	5.0%	3.5%	55.0%	200.0%	10.0%	0.1%	0.5%
Missing Sources	0.0%	0.0%	15.0%	0.0%	0.0%	0.0%	0.0%	0.0%	2.5%
Total	5.7%	3.1%	19.5%	3.5%	80.0%	128.5%	10.0%	6.5%	7.5%
HFCs, PFCs, SF6									
HFCs, PFCs, SF6	2.2%	4.5%	2.4%	0.9%	13.8%	15.5%	2.5%	0.5%	0.6%
Missing Sources	0%	0.0%	10.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.2%
Total	2.2%	4.5%	12.4%	0.9%	13.8%	15.5%	2.5%	0.5%	0.6%
Total-All Sources	100.0%	2.0%	6.4%	1.1%	9.2%	11.0%	1.8%	13.2%	12.9%

Notes: The "low" and "high" bias errors provide a subjective estimate of the largest bias error lower or higher than the current point estimate that would be consistent with current understanding of the nature of the activity or emissions mechanism. Each value is calculated as the weighted average of the uncertainties associated with a group of sources in each category. It is calculated as a percentage of the point estimate of emissions from that source. "Random error" is a subjective estimate of the largest random error that is consistent with current understanding of the nature of the activity or emissions estimate. "Weighted uncertainty" is calculated as the square root of the sum of the squared activity factor and emissions factor errors and then multiplied by the point estimate of the share of total emissions for the source. It is calculated as a percentage of the point estimate of total 1997 U.S. emissions.

Source: Estimates prepared for *Emissions of Greenhouse Gases in the United States 1997*.

Although any single computational error will usually produce a systematic error, computational errors as a group tend to produce very small (about 0.1 percent) random errors in the estimate.⁶

⁶Every year, as this report is prepared for publication, a number of computational errors that have crept into the report are detected and fixed. Sometimes, the detected errors have been present for more than one year. The errors that have been detected are typically very small (about 0.01 to 0.1 percent of emissions) and subtle, and they tend to both raise and lower estimated emissions. EIA is not aware of any remaining computational errors, but it is assumed that any undetected errors generally are similar to, or smaller than, the errors that have been detected.

The different sources of error, as noted above, can produce random or systematic (“bias”) errors. Random errors have the appearance of “noise” in the estimate, causing random year-to-year changes in the estimate as compared with (unobservable) actual emissions. Random errors might be caused by data collection and computation errors, the inherent imprecision of metering and measurement, and timing problems. Thus, it should be difficult to distinguish the “signal” of growing or declining emissions until the magnitude of the trend exceeds the “noise” from the random fluctuations. Since, in the case of U.S. energy data, rather small trends in the underlying data can be detected, it is likely that the aggregate magnitude of random errors in U.S. energy data is small, and, in particular, smaller than bias errors.

Bias errors will produce an error of approximately the same magnitude every year. If bias errors are small, they are not likely to affect the estimates of trends. Excluded sources and changes in definition produce bias errors. “Double counting” in activity data surveys will produce upwardly biased estimates of the activity; frame errors or other forms of undercounting will produce estimates that are biased downward. Because EIA, like other statistical agencies, produces data by approximately the same methods every year, double counting and undercounting errors are likely to persist over time.

There is no reason to believe that the distribution of bias errors is symmetrical around the point estimate of the value. In fact, *a priori* or independently gathered information may indicate that the potential size and probability of the existence of bias errors may be skewed: for example, in EIA data it is likely that essentially all the transactions reported to EIA actually occurred; however, it is possible that some transactions were never reported. Thus, EIA energy data are more likely to underestimate than to overestimate actual energy consumption. Further, because there are multiple surveys of energy production and consumption, undertaken for multiple purposes, the results of the surveys can help put bounds on the extent of possible bias errors.

Bias errors can be hard to detect, and it is hard to prove either the presence or absence of bias errors. The best ways of detecting them are to use multiple methods of estimating the source series and compare the results, or to determine the range of possible values from *a priori* information. Comparison methods usually can establish “ceilings” and “floors” for bias errors: that is, it is possible to demonstrate that if the bias error exceeded a certain percent, then a separate, independently collected series must also have a bias error of the same sign. An investigation of how the data are collected may also uncover information about the magnitude or scale of potential bias errors.

The reliability of emissions data varies by category and by source. In general, estimates of carbon dioxide emissions are more reliable than estimates for other gases. It is likely that the estimate of carbon dioxide emissions is accurate to within 5 percent. Estimates of methane emissions are much more uncertain. The level of uncertainty may exceed 30 percent. Estimates of methane emissions are also likely to understate actual emissions, as a result of the exclusion of sources that are unknown or difficult to quantify such as abandoned coal mines or industrial wastewater. Nitrous oxide emissions estimates are much more unreliable than carbon dioxide or methane emissions estimates, in part because nitrous oxide emissions have been studied far less than emissions from other sources and in part because the largest apparent sources of nitrous oxide emissions are area sources that result from biological activity, which makes for emissions that are highly variable and hard to measure or characterize. The uncertainty for nitrous oxide emissions may exceed 100 percent.